

## CLAIMS

1. A piezoelectric element comprising a first electrode film, a layered piezoelectric film including a first thin piezoelectric film provided on the first electrode  
5 film and a second thin piezoelectric film provided on the first thin piezoelectric film and a second electrode film provided on the layered piezoelectric film, wherein

the layered piezoelectric film is made of rhombohedral or tetragonal perovskite oxide having preferred orientation along the (111) plane,

the first and second thin piezoelectric films are aggregates of columnar grains,  
10 respectively, which are continuously linked to each other,

the columnar grains of the second thin piezoelectric film have a larger average cross-sectional diameter than the columnar grains of the first thin piezoelectric film and

the ratio of the thickness of the layered piezoelectric film to the average cross-sectional diameter of the columnar grains of the second thin piezoelectric film is 20  
15 to 60 inclusive.

2. A piezoelectric element according to claim 1, wherein

the columnar grains of the first thin piezoelectric film have an average cross-sectional diameter of 40 nm to 70 nm inclusive and a length of 5 nm to 100 nm  
20 inclusive.

3. A piezoelectric element according to claim 1, wherein

the columnar grains of the second thin piezoelectric film have an average cross-sectional diameter of 60 nm to 200 nm inclusive and a length of 2500 nm to 5000 nm  
25 inclusive.

4. A piezoelectric element according to claim 1, wherein

the first and second thin piezoelectric films are made of oxide based on perovskite lead zirconate titanate,

the degree of (111) crystal orientation of the first thin piezoelectric film is 50 % to 80 % inclusive and

5 the degree of (111) crystal orientation of the second thin piezoelectric film is 95 % to 100 % inclusive.

5. A piezoelectric element according to claim 1, wherein

the chemical composition ratio of the layered piezoelectric film is represented as

10  $[Pb]:[Zr]:[Ti] = (1+a):b:(1-b),$

the first and second thin piezoelectric films have the same value b of 0.40 to 0.60 inclusive,

the first thin piezoelectric film has a larger Pb content than the second thin piezoelectric film,

15 the first thin piezoelectric film has the value a of 0.05 to 0.15 inclusive and the second thin piezoelectric film has the value a of 0 to 0.10 inclusive.

6. A piezoelectric element according to claim 1, wherein

the layered piezoelectric film is made of lead zirconate titanate added with at least

20 one of magnesium and manganese in an amount of more than 0 and not more than 10 mol%.

7. A piezoelectric element according to claim 1, wherein

the first electrode film is made of noble metal of Pt, Ir, Pd or Ru or an alloy

25 containing the noble metal and is an aggregate of columnar grains having an average cross-sectional diameter of 20 nm to 30 nm inclusive.

8. An inkjet head comprising: a piezoelectric element according to claim 1 including a first electrode film, a layered piezoelectric film including a first thin piezoelectric film and a second thin piezoelectric film and a second electrode film stacked in this order; a diaphragm layer disposed on the second electrode film side surface of the piezoelectric element; and a pressure chamber member including a pressure chamber for containing ink which is bonded to the surface of the diaphragm layer opposite to the second electrode film, such that the ink in the pressure chamber is discharged out by displacing the diaphragm layer in the thickness direction by the piezoelectric effect of the layered piezoelectric film.

9. An inkjet head comprising: a piezoelectric element according to claim 1 including a first electrode film, a layered piezoelectric film including a first thin piezoelectric film and a second thin piezoelectric film and a second electrode film stacked in this order; a diaphragm layer disposed on the first electrode film side surface of the piezoelectric element; and a pressure chamber member including a pressure chamber for containing ink which is bonded to the surface of the diaphragm layer opposite to the first electrode film, such that the ink in the pressure chamber is discharged out by displacing the diaphragm layer in the thickness direction by the piezoelectric effect of the layered piezoelectric film.

10. An inkjet recording device comprising  
an inkjet head according to claim 8 and  
a relative movement mechanism for relatively moving the inkjet head and a recording medium, wherein

recording is carried out by discharging the ink in the pressure chamber from a nozzle hole communicating with the pressure chamber onto the recording medium while the inkjet head and the recording medium are relatively moved by the relative movement

mechanism.

11. An inkjet recording device comprising  
an inkjet head according to claim 9 and  
5 a relative movement mechanism for relatively moving the inkjet head and a  
recording medium, wherein

recording is carried out by discharging the ink in the pressure chamber from a  
nozzle hole communicating with the pressure chamber onto the recording medium while  
the inkjet head and the recording medium are relatively moved by the relative movement  
10 mechanism.

12. An angular velocity sensor comprising: a substrate including a stationary  
part and at least a pair of vibrating parts extending in a certain direction from the stationary  
part; a piezoelectric element according to claim 1 including a first electrode film, a layered  
15 piezoelectric film including a first thin piezoelectric film and a second thin piezoelectric  
film and a second electrode film stacked in this order at least on the vibrating parts of the  
substrate; and the second electrode film on each of the vibrating parts is patterned into at  
least one drive electrode for vibrating the vibrating parts in the width direction and at least  
one detection electrode for detecting deformation of the vibrating parts in the thickness  
20 direction.

13. An angular velocity sensor according to claim 12, wherein  
the columnar grains of the first thin piezoelectric film have an average  
cross-sectional diameter of 40 nm to 70 nm inclusive and a length of 5 nm to 100 nm  
25 inclusive.

14. An angular velocity sensor according to claim 12, wherein

the columnar grains of the second thin piezoelectric film have an average cross-sectional diameter of 60 nm to 200 nm inclusive and a length of 2500 nm to 5000 nm inclusive.

5           15.     An angular velocity sensor according to claim 12, wherein  
the first and second thin piezoelectric films are made of oxide based on perovskite lead zirconate titanate,  
the degree of (111) crystal orientation of the first thin piezoelectric film is 50 % to 80 % inclusive and  
10           the degree of (111) crystal orientation of the second thin piezoelectric film is 95 % to 100 % inclusive.

16.     An angular velocity sensor according to claim 12, wherein  
the chemical composition ratio of the layered piezoelectric film is represented as  
15     [Pb]:[Zr]:[Ti] = (1+a):b:(1-b),  
the first and second thin piezoelectric films have the same value b of 0.40 to 0.60 inclusive,  
the first thin piezoelectric film has a larger Pb content than the second thin piezoelectric film,  
20           the first thin piezoelectric film has the value a of 0.05 to 0.15 inclusive and  
the second thin piezoelectric film has the value a of 0 to 0.10 inclusive.

17.     An angular velocity sensor according to claim 12, wherein  
the layered piezoelectric film is made of lead zirconate titanate added with at least  
25     one of magnesium and manganese in an amount of more than 0 and not more than 10 mol%.

18. An angular velocity sensor according to claim 12, wherein  
the first electrode film is made of noble metal of Pt, Ir, Pd or Ru or an alloy  
containing the noble metal and is an aggregate of columnar grains having an average  
cross-sectional diameter of 20 nm to 30 nm inclusive.

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19. An angular velocity sensor according to claim 12, wherein  
the substrate is made of Si.

20. A method for manufacturing a piezoelectric element comprising the steps  
10 of:

forming a first electrode film on a substrate by sputtering;

forming a first thin piezoelectric film and a second thin piezoelectric film made of  
rhombohedral or tetragonal perovskite oxide successively on the first electrode film by  
sputtering to provide a layered piezoelectric film; and

15 forming a second electrode film on the layered piezoelectric film, wherein  
the step of forming the layered piezoelectric film includes the step of providing the  
layered piezoelectric film with preferred orientation along the (111) plane.

21. A method for manufacturing an inkjet head comprising the steps of:

20 forming a first electrode film on a substrate by sputtering;

forming a first thin piezoelectric film and a second thin piezoelectric film made of  
rhombohedral or tetragonal perovskite oxide successively on the first electrode film by  
sputtering to provide a layered piezoelectric film;

forming a second electrode film on the layered piezoelectric film;

25 forming a diaphragm layer on the second electrode film;

bonding a pressure chamber member for providing a pressure chamber to the  
surface of the diaphragm layer opposite to the second electrode film; and

removing the substrate after the bonding step, wherein  
the step of forming the layered piezoelectric film includes the step of providing the  
layered piezoelectric film with preferred orientation along the (111) plane.

5           22.     A method for manufacturing an inkjet head comprising the steps of:  
              forming a diaphragm layer on a pressure chamber substrate for providing a  
              pressure chamber;  
              forming a first electrode film on the diaphragm layer by sputtering;  
              forming a first thin piezoelectric film and a second thin piezoelectric film made of  
10    rhombohedral or tetragonal perovskite oxide successively on the first electrode film by  
              sputtering to provide a layered piezoelectric film;  
              forming a second electrode film on the layered piezoelectric film; and  
              forming a pressure chamber in the pressure chamber substrate; wherein  
              the step of forming the layered piezoelectric film includes the step of providing the  
15    layered piezoelectric film with preferred orientation along the (111) plane.

              23.     A method for manufacturing an angular velocity sensor comprising the  
              steps of:  
              forming a first electrode film on a substrate by sputtering;  
20           forming a first thin piezoelectric film and a second thin piezoelectric film made of  
              rhombohedral or tetragonal perovskite oxide successively on the first electrode film by  
              sputtering to provide a layered piezoelectric film;  
              forming a second electrode film on the layered piezoelectric film;  
              patterning the second electrode film into a drive electrode and a detection  
25    electrode;  
              patterning the layered piezoelectric film and the first electrode film; and  
              patterning the substrate to provide a stationary part and a vibrating part, wherein

the step of forming the layered piezoelectric film includes the step of providing the layered piezoelectric film with preferred orientation along the (111) plane.

24. A piezoelectric element according to claim 1 further comprising an orientation control film disposed between the first electrode film and the first thin piezoelectric film, wherein

the orientation control film is made of cubic or tetragonal perovskite oxide having preferred orientation along the (111) plane.

25. A piezoelectric element according to claim 24, wherein the columnar grains of the first thin piezoelectric film have an average cross-sectional diameter of 40 nm to 70 nm inclusive and a length of 5 nm to 100 nm inclusive.

26. A piezoelectric element according to claim 24, wherein the columnar grains of the second piezoelectric film have an average cross-sectional diameter of 60 nm to 200 nm inclusive and a length of 2500 nm to 5000 nm inclusive.

27. A piezoelectric element according to claim 24, wherein the first and second thin piezoelectric films are made of oxide based on perovskite lead zirconate titanate,

the degree of (111) crystal orientation of the first thin piezoelectric film is 50 % to 80 % inclusive and

the degree of (111) crystal orientation of the second thin piezoelectric film is 95 % to 100 % inclusive.

28. A piezoelectric element according to claim 24, wherein  
the chemical composition ratio of the layered piezoelectric film is represented as  
 $[Pb]:[Zr]:[Ti] = (1+a):b:(1-b)$ ,

the first and second thin piezoelectric films have the same value b of 0.40 to 0.60  
5 inclusive,

the first thin piezoelectric film has a larger Pb content than the second thin  
piezoelectric film,

the first thin piezoelectric film has the value a of 0.05 to 0.15 inclusive and

the second thin piezoelectric film has the value a of 0 to 0.10 inclusive.

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29. A piezoelectric element according to claim 24, wherein

the orientation control film is made of oxide based on perovskite lead lanthanum  
zirconate titanate and

the degree of (111) crystal orientation of the orientation control film is 50 % or  
15 more.

30. A piezoelectric element according to claim 24, wherein

the chemical composition ratio of the orientation control film is represented as  
 $[Pb]:[La]:[Zr]:[Ti] = x \times (1-z):z:y:(1-y)$ ,

20 the value x is 1.0 to 1.20 inclusive,

the value y is 0 to 0.20 inclusive and

the value z is more than 0 and not more than 0.30.

31. A piezoelectric element according to claim 24, wherein

25 the orientation control film is made of lead lanthanum zirconate titanate added  
with at least one of magnesium and manganese in an amount of more than 0 and not more  
than 10 mol%.

32. A piezoelectric element according to claim 24, wherein  
the layered piezoelectric film is made of lead zirconate titanate added with at least  
one of magnesium and manganese in an amount of more than 0 and not more than 10  
5 mol%.

33. A piezoelectric element according to claim 24, wherein  
the first electrode film is made of noble metal of Pt, Ir, Pd or Ru or an alloy  
containing the noble metal and is an aggregate of columnar grains having an average  
10 cross-sectional diameter of 20 nm to 30 nm inclusive.

34. An inkjet head comprising: a piezoelectric element according to claim 24  
including a first electrode film, an orientation control film, a layered piezoelectric film  
including a first thin piezoelectric film and a second thin piezoelectric film and a second  
15 electrode film stacked in this order; a diaphragm layer disposed on the second electrode  
film side surface of the piezoelectric element; and a pressure chamber member including a  
pressure chamber for containing ink which is bonded to the surface of the diaphragm layer  
opposite to the second electrode film, such that the ink in the pressure chamber is  
discharged out by displacing the diaphragm layer in the thickness direction by the  
20 piezoelectric effect of the layered piezoelectric film.

35. An inkjet head comprising: a piezoelectric element according to claim 24  
including a first electrode film, an orientation control film, a layered piezoelectric film  
including a first thin piezoelectric film and a second thin piezoelectric film and a second  
25 electrode film stacked in this order; a diaphragm layer disposed on the first electrode film  
side surface of the piezoelectric element; and a pressure chamber member including a  
pressure chamber for containing ink which is bonded to the surface of the diaphragm layer

opposite to the first electrode film, such that the ink in the pressure chamber is discharged out by displacing the diaphragm layer in the thickness direction by the piezoelectric effect of the layered piezoelectric film.

5           36.     An inkjet recording device comprising  
            an inkjet head according to claim 34 and  
            a relative movement mechanism for relatively moving the inkjet head and a  
recording medium, wherein  
            recording is carried out by discharging the ink in the pressure chamber from a  
10     nozzle hole communicating with the pressure chamber onto the recording medium while  
the inkjet head and the recording medium are relatively moved by the relative movement  
mechanism.

            37.     An inkjet recording device comprising  
15     an inkjet head according to claim 35 and  
            a relative movement mechanism for relatively moving the inkjet head and a  
recording medium, wherein  
            recording is carried out by discharging the ink in the pressure chamber from a  
nozzle hole communicating with the pressure chamber onto the recording medium while  
20     the inkjet head and the recording medium are relatively moved by the relative movement  
mechanism.

            38.     An angular velocity sensor comprising: a substrate including a stationary  
part and at least a pair of vibrating parts extending in a certain direction from the stationary  
25     part; a piezoelectric element according to claim 24 including a first electrode film, an  
orientation control film, a layered piezoelectric film including a first thin piezoelectric film  
and a second thin piezoelectric film and a second electrode film stacked in this order at

least on the vibrating parts of the substrate; and the second electrode film on each of the vibrating parts is patterned into at least one drive electrode for vibrating the vibrating parts in the width direction and at least one detection electrode for detecting deformation of the vibrating parts in the thickness direction.

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39. An angular velocity sensor according to claim 38, wherein  
the columnar grains of the first thin piezoelectric film have an average cross-sectional diameter of 40 nm to 70 nm inclusive and a length of 5 nm to 100 nm inclusive.

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40. An angular velocity sensor according to claim 38, wherein  
the columnar grains of the second piezoelectric film have an average cross-sectional diameter of 60 nm to 200 nm inclusive and a length of 2500 nm to 5000 nm inclusive.

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41. An angular velocity sensor according to claim 38, wherein  
the first and second thin piezoelectric films are made of oxide based on perovskite lead zirconate titanate,

the degree of (111) crystal orientation of the first thin piezoelectric film is 50 % to  
20 80 % inclusive and

the degree of (111) crystal orientation of the second thin piezoelectric film is 95 %  
to 100 % inclusive.

42. An angular velocity sensor according to claim 38, wherein  
25 the chemical composition ratio of the layered piezoelectric film is represented as  
 $[Pb]:[Zr]:[Ti] = (1+a):b:(1-b),$

the first and second thin piezoelectric films have the same value b of 0.40 to 0.60

inclusive,

the first thin piezoelectric film has a larger Pb content than the second thin piezoelectric film,

the first thin piezoelectric film has the value a of 0.05 to 0.15 inclusive and

5 the second thin piezoelectric film has the value a of 0 to 0.10 inclusive.

43. An angular velocity sensor according to claim 38, wherein

the orientation control film is made of oxide based on perovskite lead lanthanum zirconate titanate and

10 the degree of (111) crystal orientation of the orientation control film is 50 % or more.

44. An angular velocity sensor according to claim 38, wherein

the chemical composition ratio of the orientation control film is represented as

15  $[Pb]:[La]:[Zr]:[Ti] = x \times (1-z):z:y:(1-y),$

the value x is 1.0 to 1.20 inclusive,

the value y is 0 to 0.20 inclusive and

the value z is more than 0 and not more than 0.30.

20 45. An angular velocity sensor according to claim 38, wherein

the orientation control film is made of lead lanthanum zirconate titanate added with at least one of magnesium and manganese in an amount of more than 0 and not more than 10 mol%.

25 46. An angular velocity sensor according to claim 38, wherein

the layered piezoelectric film is made of lead zirconate titanate added with at least one of magnesium and manganese in an amount of more than 0 and not more than 10

mol%.

47. An angular velocity sensor according to claim 38, wherein  
the first electrode film is made of noble metal of Pt, Ir, Pd or Ru or an alloy  
5 containing the noble metal and is an aggregate of columnar grains having an average  
cross-sectional diameter of 20 nm to 30 nm inclusive.

48. An angular velocity sensor according to claim 38, wherein  
the substrate is made of Si.

10 49. A method for manufacturing a piezoelectric element comprising the steps  
of:

forming a first electrode film on a substrate by sputtering;

15 forming an orientation control film made of cubic or tetragonal perovskite oxide  
on the first electrode film by sputtering;

forming a first thin piezoelectric film and a second thin piezoelectric film made of  
rhombohedral or tetragonal perovskite oxide successively on the orientation control film  
by sputtering to provide a layered piezoelectric film;

forming a second electrode film on the layered piezoelectric film, wherein

20 the step of forming the orientation control film includes the step of providing the  
orientation control film with preferred orientation along the (111) plane and

the step of forming the layered piezoelectric film includes the step of providing the  
layered piezoelectric film with preferred orientation along the (111) plane by the  
orientation control film.

25 50. A method for manufacturing an inkjet head comprising the steps of:

forming a first electrode film on a substrate by sputtering;

forming an orientation control film made of cubic or tetragonal perovskite oxide on the first electrode film by sputtering;

forming a first thin piezoelectric film and a second thin piezoelectric film made of rhombohedral or tetragonal perovskite oxide successively on the orientation control film  
5 by sputtering to provide a layered piezoelectric film;

forming a second electrode film on the layered piezoelectric film;

forming a diaphragm layer on the second electrode film;

bonding a pressure chamber member for providing a pressure chamber to the surface of the diaphragm layer opposite to the second electrode film; and

10 removing the substrate after the bonding step, wherein

the step of forming the orientation control film includes the step of providing the orientation control film with preferred orientation along the (111) plane and

the step of forming the layered piezoelectric film includes the step of providing the layered piezoelectric film with preferred orientation along the (111) plane by the  
15 orientation control film.

51. A method for manufacturing an inkjet head comprising the steps of:

forming a diaphragm layer on a pressure chamber substrate for providing a pressure chamber;

20 forming a first electrode film on the diaphragm layer by sputtering;

forming an orientation control film made of cubic or tetragonal perovskite oxide on the first electrode film by sputtering;

forming a first thin piezoelectric film and a second thin piezoelectric film made of rhombohedral or tetragonal perovskite oxide successively on the orientation control film  
25 by sputtering to provide a layered piezoelectric film;

forming a second electrode film on the layered piezoelectric film; and

forming a pressure chamber in the pressure chamber substrate; wherein

the step of forming the orientation control film includes the step of providing the orientation control film with preferred orientation along the (111) plane and

the step of forming the layered piezoelectric film includes the step of providing the layered piezoelectric film with preferred orientation along the (111) plane by the  
5 orientation control film.

52. A method for manufacturing an angular velocity sensor comprising the steps of:

forming a first electrode film on a substrate by sputtering;

10 forming an orientation control film made of cubic or tetragonal perovskite oxide on the first electrode film by sputtering;

forming a first thin piezoelectric film and a second thin piezoelectric film made of rhombohedral or tetragonal perovskite oxide successively on the orientation control film by sputtering to provide a layered piezoelectric film;

15 forming a second electrode film on the layered piezoelectric film;

patterning the second electrode film into a drive electrode and a detection electrode;

patterning the layered piezoelectric film, the orientation control film and the first electrode film; and

20 patterning the substrate to provide a stationary part and a vibrating part, wherein

the step of forming the orientation control film includes the step of providing the orientation control film with preferred orientation along the (111) plane and

the step of forming the layered piezoelectric film includes the step of providing the layered piezoelectric film with preferred orientation along the (111) plane by the  
25 orientation control film.